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Open-File Report 87-6F

Investigation of Relative Permeability Correlations for Multiphase Fluid Flow in Porous Media

Dr. David N. Sawyer

1987

The Mississippi Mineral Resources Institute
University, Mississippi 38677

FINAL REPORT

Investigation of Relative Permeability Correlations for Multiphase Fluid Flow in Porous Media

David N. Sawyer

Mississippi State University

29 August, 1987

MMRI #87-6F

USBM #01164128

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ABSTRACT

The major objectives of this study were (1) to determine what equipment is necessary to conduct well-designed experiments in order to generate the data necessary to arrive at a set of generalized relative permeability correlations, (2) to estimate the cost of equipment and to generate the data, and (3) to determine the length of time necessary to generate a reasonable amount of data.

After a thorough search of the literature, a detailed analysis of existing data and visits to several commercial laboratories and major oil company research laboratories, a tabulated list of equipment, equipment suppliers and equipment costs was made. It appears that at least $100,000.00 will be required for equipment purchase and fabrication in order to establish a minimal experimental research program.

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

This work is an extension of work begun July 1, 1985 and reported in Reference (1). In that work existing relative permeability data were collected and analyzed in order to determine if adequate generalized relative permeability relations could be found. Our general conclusion was that it is not possible to build generalized correlations to predict relative permeabilities with anywhere near the accuracy and precision we need with existing data. The literature review and analysis led to the conclusion that there are several variables which affect the relative permeability relations in two phase systems which have not been accounted for in the past. It will be necessary to set-up an experimental program which accounts for those variables if adequate correlations are to be obtained.

RESULTS

The laboratory equipment needed to investigate multiphase flow characteristics of consolidated porous media is listed in the appendix. Price estimates and manufacturers of this equipment are also listed.

Investigations will involve determining relative permeability curves and measuring the corresponding rock-fluid variables that influence the curves. This procedure is illustrated in Figure 1. This diagram illustrates the major steps that must be taken to measure relative permeability and the corresponding rock-fluid variables. At each step the values that must be measured (or calculated) to determine relative permeability have been clearly indicated.

The basic design of the core assembly illustrated in Figure 4 was presented by Donaldson, et al. (Reference 2). This assembly allows a variety of sample lengths to be tested, and it can be used (in conjunction with equipment listed in Tables 1 and 2) to make either steady state or dynamic relative permeability tests. If the recommended metering pump is used, saturations (steady state method) may be determined from material balance calculations. Thus, the problems associated with gravimetrically determining saturations are eliminated.

The components needed to perform each step are listed in Table 1. The number listed under the COST heading is the amount of money that is needed to buy the equipment that is essential for performing the corresponding procedural step. The laboratory equipment has been divided into two classes: primary and accessories. The Hassler sleeve, end pieces and injection pieces are labeled primary. All the other parts are labeled accessories.

The equipment name, price estimate, and manufacturer of individual components that are needed are listed in Table 2. Table 1 refers to these components by number. The addresses of the manufacturers that make these components are listed in Table 3. Some of the more interesting components are illustrated in Figures 2, 3, 4, 5, 6, 7, 8, and 9.

The sum of these costs is just under $90,000. I estimate the time required by our technician to prepare the room, receive and set-up the equipment would cost approximately $10,000 which gives a total cost to purchase the equipment and materials and set it up of $100,000. This is the minimum case. This is the absolute least amount of equipment necessary to start a meaningful research program to obtain two phase relative permeability data using the steady state method described in reference (1). This will be referred to as Option 1.

The equipment to obtain data by the unsteady state method (Reference 1) could be added to the abovementioned list for approximately $65,000. (Reference 3). This case will be referred to as Option 2.

I estimate (Table 4) the annual cost under Option 1 with one graduate student to be $55,000. With two graduate students the estimated cost rises to $87,800. Two graduate students would be a maximum with this limited equipment. For either one or two graduate students, the annual cost would not change much between Option 1 and Option 2. Option 2 would allow for a third graduate student with a total estimated annual cost of $115,000.

The next major step up in the investigation of multiphase fluid flow in porous media would be the addition of equipment which would allow the study of fluid distribution. This objective can be achieved by the use of a Computer Assisted Tomography Scan, commonly known in the medical profession as a CAT-SCAN. In the last 3-4 years a new generation of cat scans have come on the market which make the older models obsolete for use on humans. As a result there is a surplus of the older models. Many hospitals and other medical facilities will "give away" the older models if the receiver pays the relocation cost (which runs $20-25,000). However, the acquisition cost is small compared to the annual operating cost of this equipment. The service contract is on the order of $50-60,000 per year. A skilled technician to operate the machine will require a salary plus benefits of about $20,000.

As an indication of what can be spent on research equipment, I will briefly describe the system in the ARCO Oil and Gas Company Research Laboratory at Plano, Texas. They have a completely computer-controlled, automated, unsteady state system for obtaining relative permeability data using live reservoir fluids at reservoir temperature and pressure. This system cost on the order of $1.1 million to build. The system is not expensive to operate as it is capable of running 24 hours a day, 365 days a year with virtually no human attention. Seven or eight graduate students would be able to generate data year-round with a system like this.

CONCLUSIONS

While there is practically no upper limit as to what can be spent on equipment, the minimum cost necessary to initiate a research project of this type is $100,000. For the first graduate student the annual cost will be about $55,000. Each additional graduate student adds about $30,000 per year to this base cost. It is apparent from this study that a research project of this type will require not only large initial funding, but a rather large annual commitment from some source.

BIBLIOGRAPHY

1. Sawyer, D.N., "Investigation of Relative Permeability Correlations for Multiphase Fluid Flow in Porous Media", Final Report, MMRI #86-3F (USBM #G1154128), August 29, 1986.

2. Donaldson, E.C.: Personal Communication (1986).

3. Personal Communication from Core Labs, Inc., Special Core Analysis, Dallas, Texas (June, 1987).

APPENDIX

Table 1 – Equipment Reference and Corresponding Cost Estimates

PROCEDURAL STEP	EQUIPMENT LIST	COST
A - CORE PREPARATION		
Core cutting	25,26,27	$ 9,241.00
Heat treatment	32	1,700.00
Initial saturation	8,17,*18,19	8,805.00
Cleaning system	20,21,*22	325.00
		Total cost for A = $20,071.00
B - ROCK-FLUID VARIABLES		
Microstructure	28	9,700.00
Interfacial tension	23	1,400.00
Wettability	30	80.00
Fluid viscosity	4	36,378.00
Temperature	*10	80.00
		Total cost for B = $47,638.00
C - RELATIVE PERMEABILITY		
Primary parts	33,34	3,300.00
Fluid injection	*(1,2,3,5),6,7,*8	5,990.00
Collection system		
Liquid - Liquid	*5,6,12	3,170.00
Gas - Liquid	9,13	5,260.00
Miscellaneous	11,*(14,15,16,24,31),29	3,685.00
		Total cost for C = $21,405.00

* Indicates more than one is needed.

Table 2 - List of Individual Components and Corresponding Cost.

ACCESSORTES

Equipment List	Manufacturer	Price
1. Microprocessor-based Piston Pump	Cole-Paramer	$2,300.00
2. Pulse Dampener	Cole-Paramer	180.00
3. Filter	Cole-Paramer	70.00
4. High-Pressure Rolling Ball-Type Viscosimeter	Core Laboratories, Inc.	36,378.00
5. Pressure Transducer	Fisher	210.00
6. Digital Pressure Meter	Fisher	250.00
7. Pressure Regulator	Fisher	150.00
8. Pressure Gage	Fisher	70.00
9. Wet-test Gas Meter	Fisher	2,300.00
10. Thermometer	Fisher	20.00
11. Mettler Balance	Cole-Paramer	2,800.00
12. Liquid - Liquid Separation and Measurement	Design at M.S.U.	2,500.00
13. Gas - Oil Separation and Measurement	Core Laboratories, Inc. or Design at M.S.U.	2,960.00
14. Stainless Steel Tubing (1-ft)	Cole-Paramer	6.00
15. Stainless Steel Union Tee	Cole-Paramer	40.00
16. Stainless Steel Union	Cole-Paramer	15.00
17. Vacuum Pump	Cole-Paramer	400.00
18. Vacuum Grease (1-tube)	Cole-Paramer	9.00
19. High Pressure Saturator	Core laboratories, Inc. or Design at M.S.U.	8,308.00
20. Soxhlet Extraction Apparatus	Fisher	150.00

Table 2 (continued) - List of Individual Components and Corresponding Cost.

	Equipment List	Manufacturer	Price
21.	Heating Mantel for Extractor	Fisher	100.00
22.	Toluene (1 - Liter)	Fisher	15.00
23.	Interfacial Tensiometer	Central Scientific Co.	1,400.00
24.	Micro-calipers	Fisher	40.00
25.	Diamond Tooled Saw	Core Laboratories, Inc.	5,166.00
26.	Diamond Tooled Drill	Core Laboratories, Inc.	3,670.00
27.	Diamond Bit	Core Laboratories, Inc.	405.00
28.	Capillary Pressure Test Apparatus	Porous Materials, Inc.	9,700.00
29.	Fluids and Chemicals (oil, salt, gas, sandstone, etc)		350.00
30.	Glassware for Arnott Test	Fisher	80.00
31.	Stop Watch	Fisher	150.00
32.	Furnace	Cole-Paramer	1,700.00

PRIMARY
Components (All manufactured at M.S.U.)

33. Hassler Sleeve - Core assembly
outer casing

34. Injection Pieces

Design alterations (if needed) and machine drawings	800.00
Material and machine labor	2,500.00

TABLE 3 - Addresses of Companies Listed

1. Fisher

U.S. branch sales offices

Atlanta
2775 Pacific Drive
P.O. Box 4829
Norcorss, GA 30091
(404) 449-5050

2 **Cole-Paramers Instrument Company**

7425 North Oak Park Avenue
Chicago, IL 60648

3. **Scientific Products**

155 Brookhollow Esplanade
Harahan, LA 70183
(800) 535-7323/33

4. **Central Scientific Company**

11222 Melrose Avenue, Franklin Park
Chicago, IL 60131
(312) 451-0150

5. **Porous Materials, Inc.**

Cornell Industries Research Park
Building 4
Ithaca, NY 14850
(607) 257-4267

6. **Core Laboratories, Inc.**

7501 Stemmons Freeway
Box 47547
Dallas, TX 75247
(214) 631-8270

TABLE 4 - Estimated Budgets Using Option 1

1 Graduate student, full-time, 12 months
1 Faculty member, 1/4 time, 9 months, full-time 3 months
1 Technician (part-time), 12 months

Graduate Student Salary	$12,000.00
Faculty Member Salary	26,000.00
Technician Salary	3,600.00
Fringe Benefits (19% salary, except grad. student)	5,600.00
Equipment Replacement and Repair	2,500.00
Consumable Supplies	500.00
Computer Time	1,500.00
Utilities	800.00
Laboratory Supplies	2,500.00
‘ TOTAL	$55,000.00

2 Graduate students, full-time, 12 months
1 Faculty member, 1/2 time, 9 months, full-time 3 months
1 Technician (part-time), 12 months

Graduate Student Salary (2)	$24,000.00
Faculty Member Salary	37,000.00
Technician Salary	3,600.00
Fringe Benefits (19% salary, except grad, student)	7,700.00
Equipment Replacement and Repair	5,000.00
Consumable Supplies	1,000.00
Computer Time	3,000.00
Utilities	1,500.00
Laboratory Supplies	5,000.00
"~ TOTAL	$87,800.00

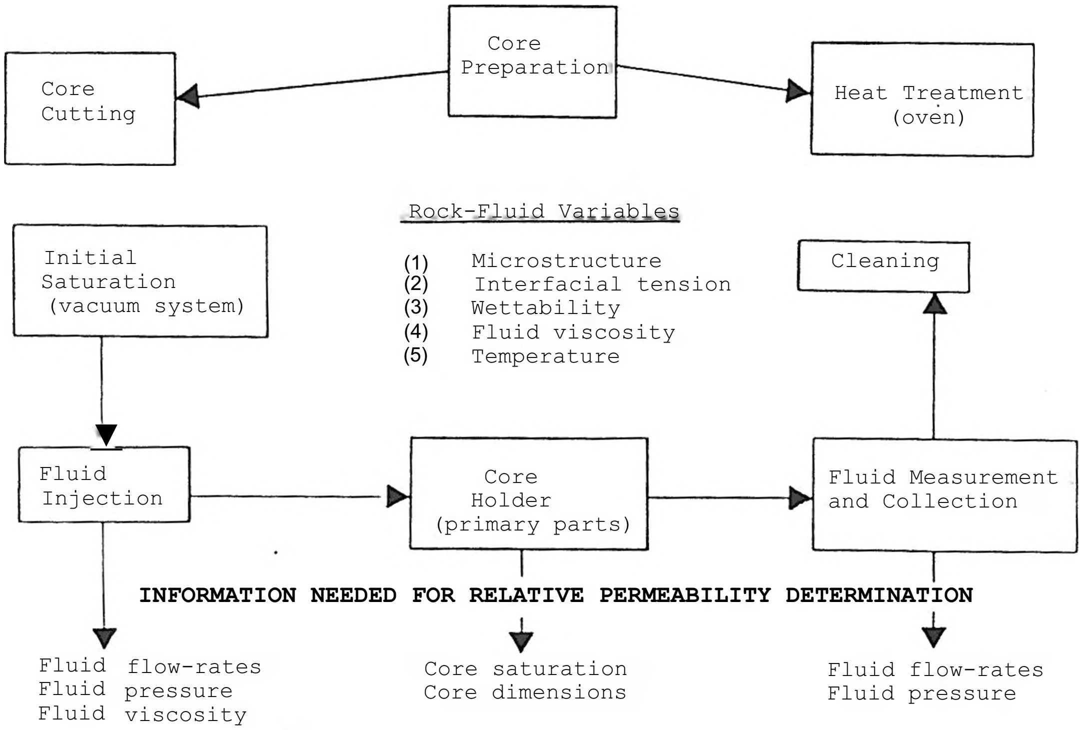

Figure 1 – Major Steps in Determining Relative Permeability and Influencing Variables.

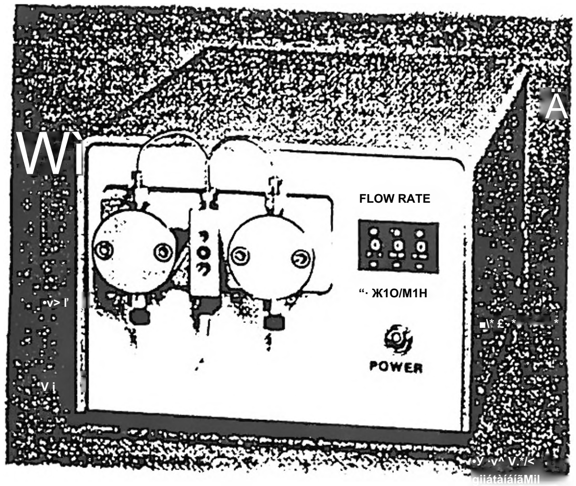

Figure 2 - Metering Pump
(Pump will deliver .2 to 9.9 ml/min with a maximum differential pressure of 10,000 psi)

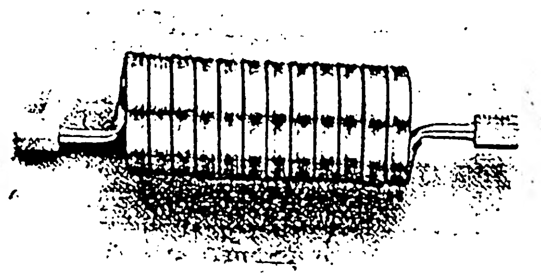

Figure 3 - Pulse Dampener

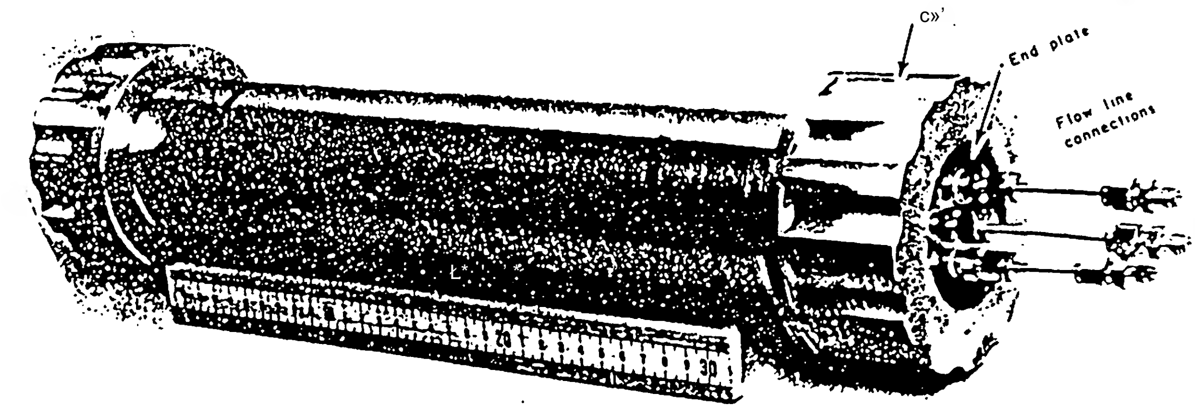

Figure 4 - Outer Casing of Hassler Sleeve

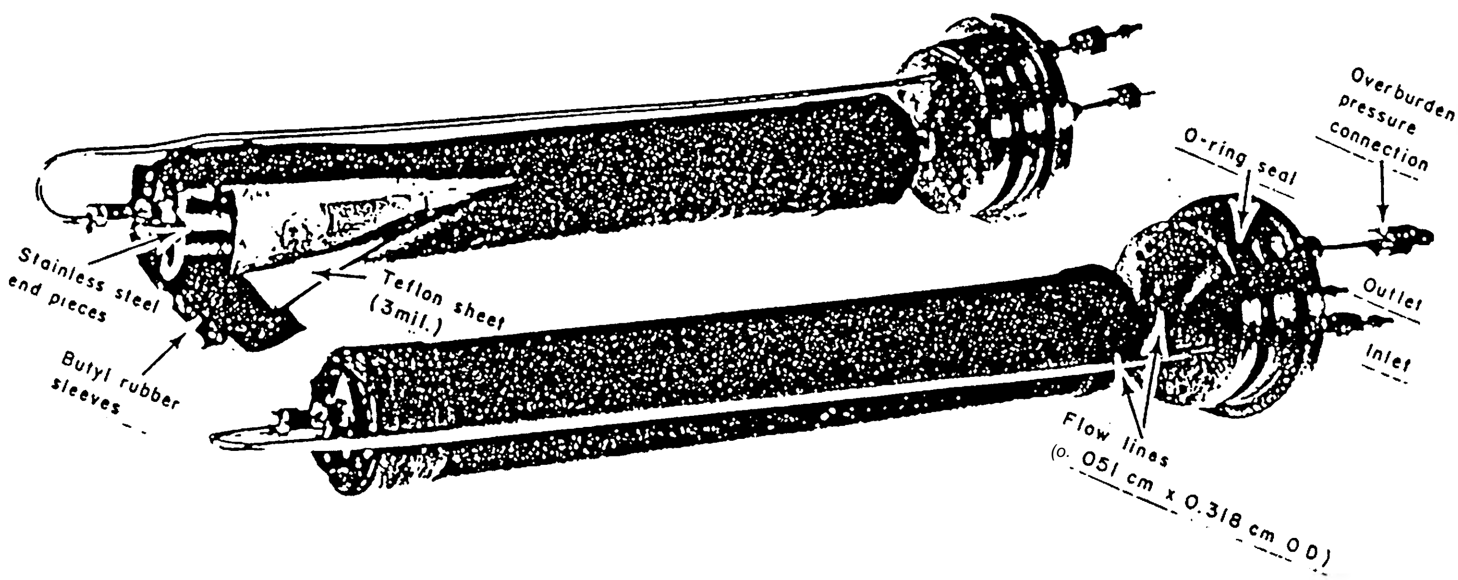

Figure 5 - Core Assembly

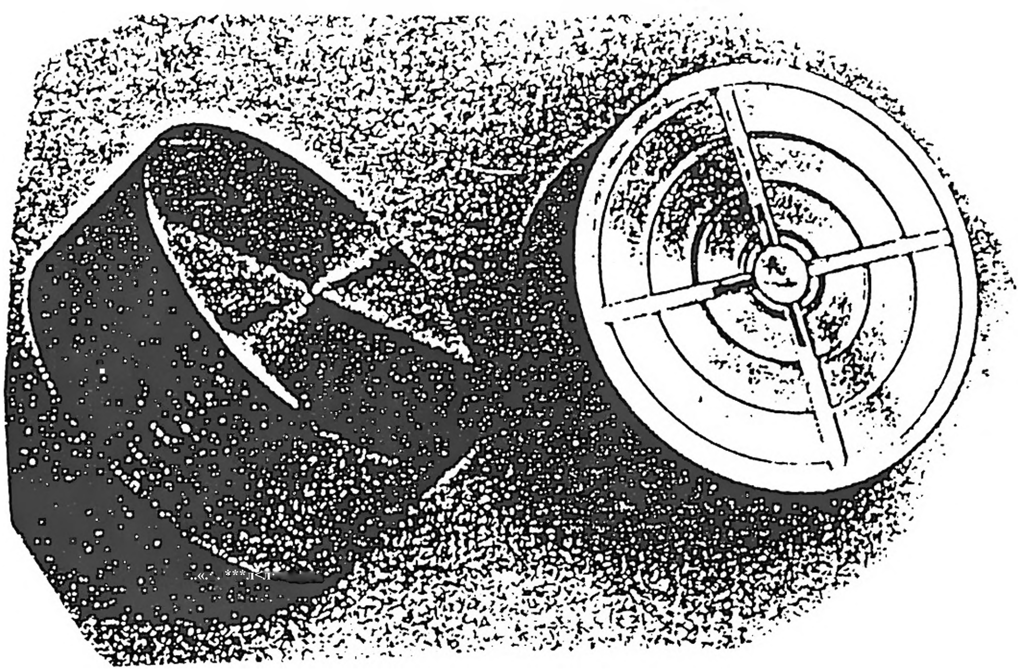

Figure 6 - Injection Pieces

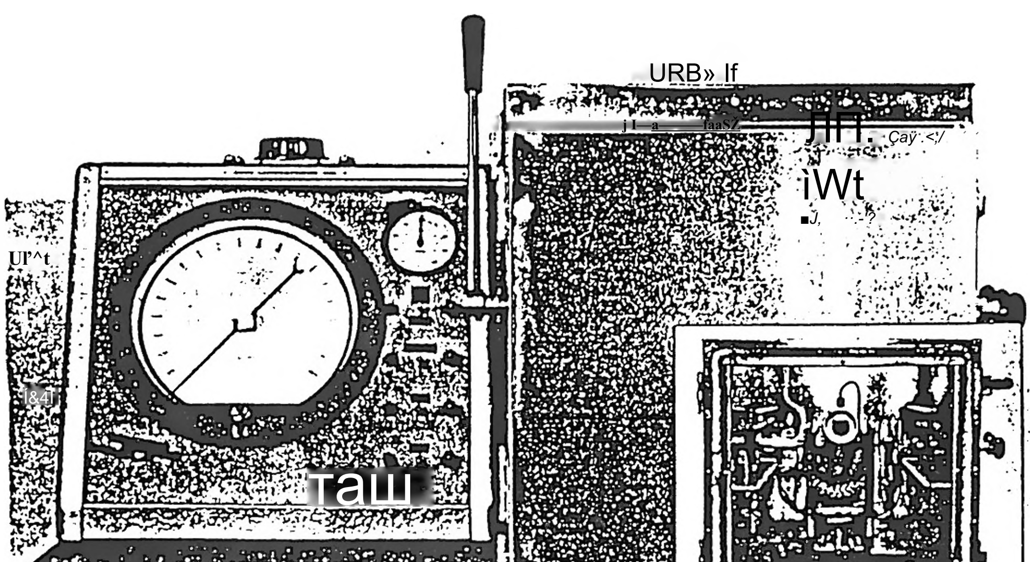

Figure 7 - High-Pressure Rolling Ball-Type Viscosimeter

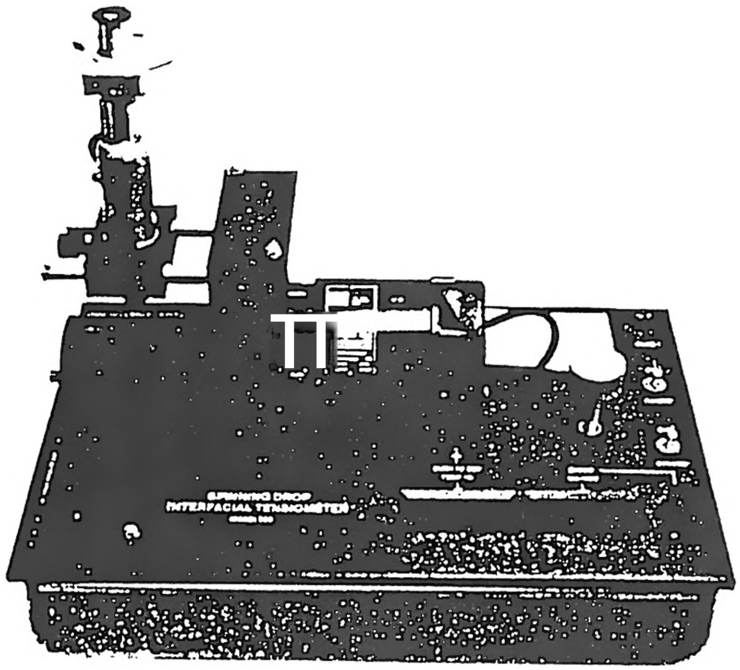

Figure 8 - Interfacial Tensoimeter

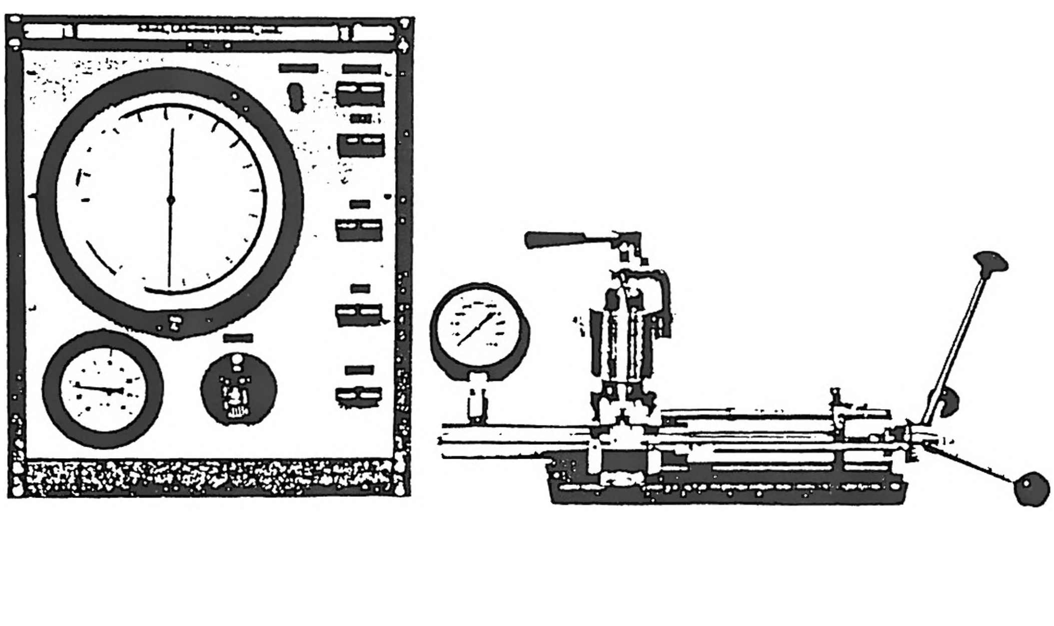

Figure 9 - Capillary Pressure Test Apparatus